

Temperature Effect on Performance of Different Solar Cell Technologies

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ABSTRACT

One of the main parameters that affect the solar cell performance is cell temperature; the solar cell output decreases with the increase of temperature. Therefore, it is important to select the proper solar cell technology that performs better at a specified location considering its average temperatures. In addition, the solar cell performance is directly reflected on the overall economics of the project. This paper is proposed to evaluate the variations in the performance of different solar cell technologies related to the temperature in Amman, Jordan. Field data of weather station and three PV systems (Poly-crystalline, Mono-crystalline and Thin-film) of identical design parameters were collected from Test Field Project at Applied Science Private University, Shafa Badran, Amman, Jordan. These data were analysed in the following way. estimated specific energy yield (kWh/kWp) for the three different PV systems was calculated depending on the measured value of solar irradiance and technical specifications of the installed solar panels and inverters, then the actual energy yield at different temperatures over one year was compared with the estimated value, so the deviations could be determined and actual temperature coefficients for energy yield could be calculated, knowing that the three PV Systems have identical design parameters (tilt angle, azimuth angle, type and dimensions of mounting structure and inverter size) and same cleaning method and schedule. It was found that the thin-film solar panels are less affected by temperature with temperature coefficient of -0.0984%, and -0.109%, -0.124% for Mono-crystalline and Poly-crystalline respectively. These results can be implemented in the preliminary design steps, specifically in the selection of the solar cell technology to be installed in a specific location.

INTRODUCTION

Solar cells directly convert sunlight into electricity, as a result of the photovoltaic effect and the fact they consist of doped semiconductor materials forming a P-N Junction. Different semiconductor materials can be used in solar cells, including Crystalline Silicon (c-Si) and Amorphous Silicon (a-Si). The c-Si can be either Poly-crystalline or Mono-crystalline, depending on the manufacturing processes implemented.

The solar cell performance is directly affected by the weather conditions, mainly the solar irradiance and temperature [Sauer et al. 2007]. The effect of decreasing irradiance involves a drop in solar cell output current and voltage, and the effect of increasing cell temperature consists in

a slight increase in the output current and considerable decrease in output voltage, resulting in an overall decrease in output power. These effects are illustrated in Figures 1 and 2.

Solar panels are tested in laboratory setting under Standard Test Conditions (STC) of 1000 W/m² incident solar irradiance, 25°C cell temperature, 0.0 wind speed and 1.5 air mass spectrum. STC rarely exist in actual outdoor conditions, specifically the cell temperature, since most of the time, under actual operating conditions, will be much higher than 25°C, especially in hot climates [Pless et al. 2005]; hence, they cannot be used to estimate the actual performance and energy yield of a PV System.

Different solar cell technologies have different responses to the temperature variations, and

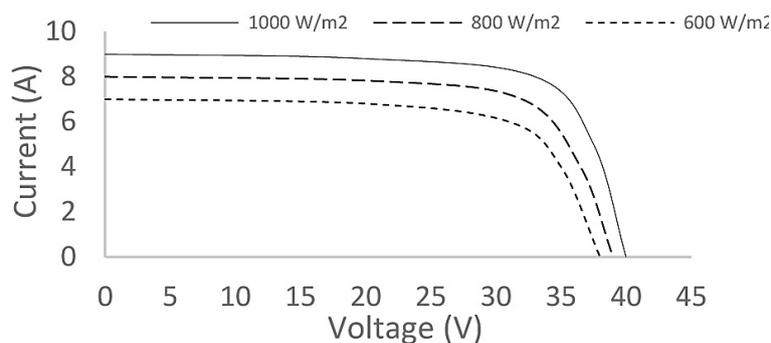


Figure 1. Effect of Irradiance on Solar Cell I-V Curve

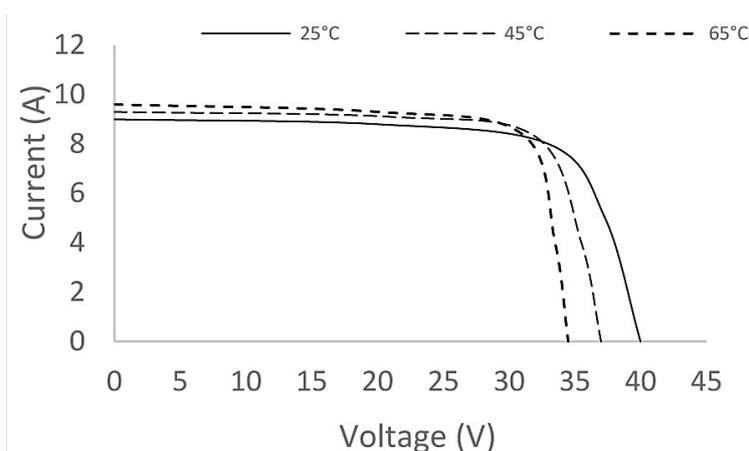


Figure 2. Effect of Temperature on Solar Cell I-V Curve

this difference in response has been widely investigated in the literature.

Hamrouni et al. [2008] investigated the effect of ambient temperature and solar irradiance on the performance of solar pumping system and concluded that high ambient temperature decreased the pump flow rate and overall system efficiency. Priyanka and Ravindra [2012] studied the temperature dependence (in the range of 273–523 K) of key characteristics of solar cell, namely the short circuit current density, open circuit voltage, fill factor and efficiency, considering solar cells of different semiconductor materials such as Si, GaAs, InP, CdTe and CdS. They concluded that the overall performance decreases with the increase of temperature.

Dubey et al. [2013] reviewed literature investigations on the relation between cell temperature and solar cell performance, and concluded that care must be taken when using the expressions found in the literature to estimate solar cell temperature, because those expressions apply only for restricted mounting geometry. Tobnaghi et al. [2013] experimentally obtained coefficients to estimate the variations in the electrical parameters of

solar cells with temperature, and the most significant coefficient obtained described the decrease of maximum power output with the increase of temperature, with coefficient of $-0.005 \text{ mW}/^\circ\text{C}$.

Je et al. [2014] monitored the performance of different solar cell technologies in tropical climate in Singapore, including mono-crystalline Si, heterojunction crystalline Si, multicrystalline Si, double-junction Si, single-junction/double-junction amorphous Si, CdTe and CIGS. In this work, the degradation rates were evaluated using Statistical decomposition methods. The degradation rates for mono-crystalline Si modules were found to be equal or less than -0.8% per year, -1% for multicrystalline Si modules, -2% for amorphous Si, micromorph Si, and CdTe modules and -6% for CIGS modules.

Cañete et al. [2014] studied the performance of four different technologies in southern Spain; it was found that the performance of thin-film modules is better in summer, while in the case of poly-crystalline modules, their performance is better in winter.

This paper investigates the temperature effect in Amman, Jordan, on mono-crystalline,

poly-crystalline and a-Si modules, through estimating the effect on annual energy yield. The actual temperature coefficients are calculated and compared to the coefficients in the datasheets of the solar panels. This work is useful in the preliminary design steps of a PV Systems, specifically in the selection of module technology to be implemented in the project.

DESCRIPTION OF PV SYSTEMS AND ANALYSED DATA

PV Systems

Test Field Project at Applied Science Private University (ASU) is a unique project of its type in Jordan, with its diverse installed PV System. The project comprises seven different PV projects, all installed for research purposes. These systems are. CPV Dual-Axis Tracking System, Poly-crystalline Dual-Axis Tracking System, South Poly-crystalline PV System (S-Poly), South Mono-crystalline PV System (S-Mono), South Thin-film PV System (S-Thin-film), East-West Poly-crystalline PV System and East-West Mono-crystalline PV System. This diversity in the project offers wide research capabilities for the project, and the three south oriented PV Systems were chosen for the purpose of analysis in this paper, knowing that they are all of identical design parameters (tilt angle, azimuth angle, type and dimensions of mounting structure, length and gauge of wiring and inverter size). Technical specification of inverters and PV panels for the three systems are described in Table 1 and Table 2. Identical design parameters are outlined in Table 3. The three systems and weather station, which is 70 m apart from the PV Systems, are shown in Figures 3 to 6.

Weather Station

In addition to these three systems, the weather data were also collected from a standardized weather station in ASU offering wide range of

measured data (Figure 7) such as. ambient temperature at different levels, global, direct and diffused irradiance, wind speed and direction at different levels. Irradiance and ambient temperature at 1m level above the ground are used in this paper for the purpose of analysis.

METHODOLOGY AND CALCULATIONS

Methodology

Since all the three PV Systems are of identical design parameters and exposed to same weather conditions (irradiance, temperature and wind speed), we can assume that the difference between the actual energy yield (kWh/kWp) and estimated energy yield is primarily due to actual cell temperature (T_c) being higher (or lower) than T_c at STC, taking into account the actual incident irradiance, array size (kWp), array area and module as well as inverter efficiency.

Data and Calculations

The actual data for energy yield were extracted from the monitoring system of the three inverters and are shown in Table 4. In Table 5, average monthly values for ambient temperature (T_a) and global horizontal irradiance (GHI) is extracted from the weather station data logger. Direct horizontal irradiance (DHI) is calculated using Diffused/Global irradiance ratio in [PVGIS

Table 2. Technical Specifications of the PV Panels

Module technology	Mono-crystalline	Poly-crystalline	Thin-film
Model	YL260C-30b	YL250P-29b	NA-E125L5
P_{max} (STC)	260 W	250 W	125 W
Dimensions	1.65x0.99 m	1.65x0.99 m	1.40x1.00 m
Efficiency	15.9%	15.3%	8.9%
Temp. Coefficient for P_{max}	-0.42%/°C	-0.45%/°C	-0.24%/°C
Number of Modules installed	20	20	40

Table 1. Technical Specifications of the Inverters

System	Model	Size (kW _{AC})	Max. efficiency
S-Poly	SB 5000TL-20	5	97%
S-Mono	SB 5000TL-20	5	97%
S-Thin-film	SMC 5000A	5	96.1%

Table 3. Identical Design Parameters

Tilt angle	11°
Azimuth angle	0° (Directly south oriented)
Type of Mounting Structure	Ground Mounted (Elevated Structure)



Figure 3. PV Systems



Figure 5. S-Thin-film



Figure 4. S-Mono (left), S-Poly (right)



Figure 6. ASU Weather Station

European Communities, 2001–2012]. The data of wind speed is neglected, since T_c is taken into account in the calculations, and T_c is directly affected by wind speed [Dubey 2013].

Estimated energy yield (kWh/kWp/month) can be calculated using equation 1.

$$E_{estimated} = G \times A \times \eta \times t / P_{max} \quad (1)$$

where: G is average monthly global incident irradiance (kW/m^2),
 A is array total area (m^2),
 η is module efficiency,
 t is total number of hours per month and
 P_{max} is array maximum power (kWp).
 Global incident irradiance is calculated using the following formula [Gulin et al. 2013] and solar angles in [PVSystem V6.43] form PVSystem software.

$$G = B + D + R \quad (2)$$

RESULTS AND CONCLUSION

Where B is direct irradiance in tilted and aligned surface, D is diffuse irradiance on tilted and aligned surface and R is reflection irradiance on tilted and aligned surface. In the calculations,

D and R are assumed as one component since a pyranometer measures both together. Table 6 shows the results of applying equations 1 and 2.

Calculating T_c is critical in determining the amount of deviation between the actual and theoretical energy yield at STC. Hence, T_c is calculated using the formulae found in [SMA Solar Academy], which simply states that if the module is free mounted (ground mounted), T_c will be 20°C higher than the ambient temperature. Therefore, annual average increase in calculated T_c over T_c at STC was found to be 12.53°C .

Annual deviation in energy yield for the three systems was found to be 15.4%, 17.0% and 19.5% for Thin-film, Mono-crystalline and Poly-crystalline PV modules, respectively. This amount of deviation is assumed to be caused by temperature rise of 12.53°C in T_c . Then, the deviation caused by temperature rise of 1°C in T_c was calculated.

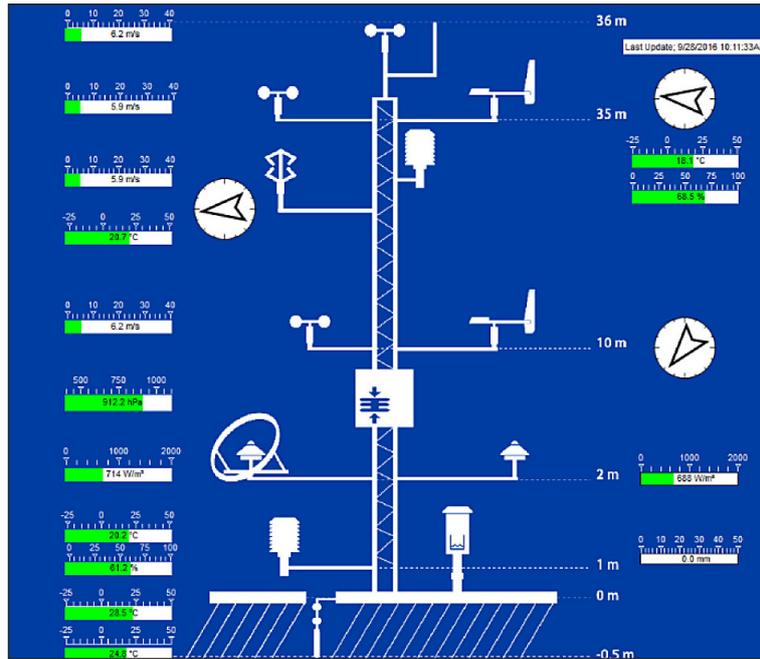


Figure 7. Data of ASU Weather Station

Table 4. Actual Energy Yield (kWh/kWp/month)

Month	S-Mono	S-Poly	S-Thin-film
January	91.52	87.73	84.84
February	122.68	118.21	118.35
March	144.03	139.85	140.74
April	172.41	168.53	176.11
May	182.01	179.5	191.62
June	192.65	190.5	201.94
July	198.04	194.68	209.45
August	186.23	181.28	197.11
September	159.69	153.5	166.66
October	146.54	139.48	150.69
November	110.01	104.24	105.92
December	86.15	83.02	79.29

Table 5. Average Monthly Weather Data

Month	T _a (°C)	GHI (W/m ²)	DHI (W/m ²)
January	6.8	116	67
February	11.5	182	106
March	13.1	212	127
April	19.4	285	182
May	19.9	302	214
June	25.5	349	269
July	25.1	344	265
August	24.9	299	227
September	22.3	262	194
October	20.2	196	135
November	14.2	150	99
December	7.5	109	68

The results demonstrated that energy yield for Thin-film PV modules is less affected by temperature than Mono-crystalline and Poly-crystalline PV modules. Temperature coefficient for Thin-film PV modules was found to be -0.0984%, which means that for each 1°C of T_c increase above that of T_c at STC, the energy yield will decrease by 0.0984%. For Mono-crystalline and Poly-crystalline PV modules, temperature coefficient was found to be -0.109% and -0.124%, respectively.

These results are good indications of how ambient temperature would affect the annual energy yield of a PV System, and they are of increasing importance for large-scale PV projects since the decrease of energy yield with temperature will be of greater amount.

Table 6. Global Incident Irradiance and Estimated Energy Yield for PV Systems

Month	G (kW/m ²)	E _{estimated} (kWh/kWp/month)		
		S-Mono	S-Poly	S-Thin-film
January	131	97	97	97
February	199	138	139	138
March	225	167	167	167
April	294	212	212	211
May	306	228	228	227
June	351	253	253	252
July	348	259	259	258
August	309	229	230	229
September	279	201	201	200
October	216	160	160	160
November	171	123	123	123
December	126	94	94	93

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